PIP - A large solid angle detector for protons and pions

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Abstract: A ~1 sr solid angle detector for protons of up to ~200 MeV, and for pions of up to ~250 MeV energy is described. The detector has been developed to provide a charged particle trigger for use in (γ,2N) and (γ,πN) experiments with tagged photons at the MAMI-B 850 MeV electron microtron in Mainz. The design is based on a smaller detector previously used at lower energies at the 180 MeV MAMI-A accelerator. Many improvements have been made which will increase the performance of PIP with respect to the earlier detector. Positive pions which are stopped in the detector will be identified by looking for delayed pulses from the e^+ in the pion decay chain.

PIP is a PIon-Proton detector which has been developed by the Glasgow and Edinburgh nuclear physics groups for use in tagged photon experiments at the University of Mainz 840 MeV electron microtron [1]. Photons from a wide momentum acceptance tagged photon spectrometer [2] will be used to study (γ,2N) and (γ,πN) reactions. PIP will act as a trigger detector measuring the momentum vector of a resulting proton or pion. The correlated nucleon will be measured by a large solid angle time-of-flight spectrometer [3]. The design of PIP is based on a smaller detector [4] previously used for detecting protons in (γ,p) and (γ,pN) reactions at the lower energy MAMI-A accelerator. Lessons learnt from the operation of the smaller detector have been incorporated into the design of the new detector.

Figure 1 shows the layout of the experimental hall. The incident 850 MeV electron beam produces bremsstrahlung photons in a thin radiator which are then collimated in a tungsten alloy collimator before hitting the nuclear target. The main electron beam is deflected by the QD tagged photon spectrometer before being dumped in a faraday cup outside the experimental hall. The bremsstrahlung electrons are detected in an array of 353 overlapping scintillators on the spectrometer focal plane. PIP is placed

50 cm from the target to detect protons and pions from nuclear reactions. Correlated neutrons and protons are detected by an array of ~100 time-of-flight detectors on the other side of the target. The incoming and outgoing electron beams are shielded by concrete walls and measurements have shown that the room background is very small.

Figure 2 shows a detailed plan of PIP. It basically consists of 2 ΔE transmission detectors followed by 4 thick E scintillator blocks. Each successive layer is larger than the previous one to ensure that protons originating in the target and transmitted through ΔE2 will be transmitted into the following layers, and will not pass out of the edges of the detector even after allowance for multiple scattering.

ΔE1 is 1 mm thick and is formed in the arc of a circle of radius 8 cm with the target placed at its centre. The beam spot is ~2 cm diameter at the target position allowing ΔE1 to have a small radius and yet intercept all the reaction particles entering PIP. It has adiabatic twisted strip light guides to give optimum pulse height and timing resolution. The timing of the reaction and the start time of the time-of-flight detectors will be derived from this detector which is expected to have a resolution better than 1 ns FWHM.

ΔE2 consists of 4 vertical scintillators 2mm thick x 20cm wide x 42cm high. This element defines the solid angle of PIP to be ~1.0 sr, as the size of ΔE2 is less than E1. This improves on the previous detector which had ΔE2 larger than E1 and due to edge effects relied on the position calibration to define the solid angle. The thickness is also reduced wrt the previous detector and this, in conjunction with lower threshold discriminators, should reduce the low energy proton threshold from ~27 MeV to ~20 MeV. The ΔE2 strips have adiabatic twisted strip light guides to give optimum pulse height and timing resolution. The vertical position of the reaction product is determined by time difference between signals from either end of each strip. Based on the previous detector a vertical angular resolution of 5.0° FWHM is expected. The vertical opening angle is ~46°.

The E1 layer consists of 4 blocks 1 m long x 13.5 cm high x 11 cm thick, as opposed to the 3 such blocks in the previous detector. This contributes to the larger solid angle. Previously, in order to measure at forward and back angles no light guides were used. This was a mistake which resulted in non-linearity in the timing response and non-uniformity in the light collection close to the ends of each block. The new detector does use light guides, but having 4 blocks can still reach small forward angles and large backward angles by allowing the narrow photon beam to pass between the ends of the photomultiplier tubes as shown in figure 2. The horizontal opening angle is ~77° with the most forward angle accessible ~26° and the most backward ~154°. The horizontal position is again defined by time difference between signals from the two ends of each block. A horizontal angular resolution of better than 2.7° FWHM is again expected on the basis of experience with the previous detector.

The second E2 layer of scintillators consists of 4 scintillators 130 cm long x 17.5 cm x 17.5 cm. This is sufficient to stop protons of energy 215 MeV at normal incidence and of energy ~280 MeV at forward and backward angles. However, for reasons explained below, the detector will in practice only be used to measure proton energies up to ~200 MeV. Pions have a lower stopping power than protons and so two further layers E3 and E4 are used to stop pions of energies up to ~185 MeV at normal incidence and up to ~265 MeV at extreme forward and backward angles. The E3 layer consists of 5 scintillator blocks 160 cm x 17.5 cm x 17.5 cm and the E4 layer consists of 6 blocks 190 cm x 17.5 cm x 17.5 cm.

The detector is constructed in modules and is supported by a strong steel framework. It is surrounded by a 5 mm steel plate box which forms a barrier to charged particle room background and a second defence against light leaks. Further shielding will be provided if necessary but initial tests indicate this is unlikely to be required. The electronics are mounted in 4 racks directly behind the detector in order to keep the electronic delays to a minimum. The total weight of the detector assembly is ~4 tonnes.

Figure 3 shows a schematic diagram of the electronics for PIP. A hardware coincidence is taken between each end of each block or strip, and a proton trigger is formed if coincident signals are present in one E1 block, one $\Delta E2$ strip and $\Delta E1$. This selects only particles originating close to the target and very considerably reduces the background expected from a trigger produced by $\Delta E2$ and E1 alone. For each event pulse height and timing information is recorded for each end of each detector element. Pions rely for their identification on the detection of a second delayed pulse from the e^+ in the π^+ decay chain. Only second pulses in the element in which the pion stopped, or in a neighbouring element, are examined for second pulses. If such a signal is present a pion trigger is formed and the pulse height and timing information for the second pulse is recorded in a separate set of ADC's and TDC's. Fast clear signals are used to reject online further electron background if the sum $\Delta E2$ and E1 pulse heights fall below a set threshold. Likewise experiments to measure pion cross-sections may use a fast clear if the initial trigger is not followed by a second pulse indicating a pion has been detected.

Protons which stop in the E1 layer, and give no signals in subsequent layers, are separated from electrons and deuterons on the basis of their $\frac{dE}{dx}$ vs E pulse height characteristics. Treating protons which penetrate the E2 layer separately prevents the characteristic back bend in the $\frac{dE}{dx}$ vs E plot from obscuring particle identification. Additional separation of protons and deuterons from low energy electrons can be achieved using an E pulse height vs velocity graph where the velocity is calculated from the time difference measured between $\Delta E1$ and $\Delta E2$. Previous experience has shown most background electrons to be of low energy and this technique has been found to provide good discrimination. Note that the maximum energies of particles stopped in the E1 layer vary with angle from ~125 MeV in the centre to ~145 MeV at extreme forward and backward angles. Pions have a $\frac{dE}{dx}$ vs E locus which is located with the edges of the electron distribution and, as stated previously, are identified by the additional requirement of a second signal from the e^+ in the π^+ decay chain.

For protons which enter the E2 layer the best separation between protons, deuterons and pions will be achieved by using both $\Delta E2$ and E1 as $\frac{dE}{dx}$

detectors and plotting $\frac{\Delta E2}{X_{\Delta E2}} x \frac{E1}{X_{E1}}$ against E2. Again the subsequent layers will be used to veto particles which do not stop in E2, and this will prevent characteristic back bend in the graph. For pions all four E layers will be used. The requirement of a second pulse will veto pions which are not stopped in any of the four layers.

The energy of each particle will be determined by the pulse height spectra in each element which fires. To eliminate pulse height attenuation with position the geometric mean of signals from both ends of each element will be used. For protons stopped in E1 the energy calibration will be a smooth, and nearly linear, function of pulse height. However for protons stopped in E2 the situation is more complex. The pulse height in E2 is more sensitive to the proton energy than the sum of pulse heights in E1 and E2, but the calibration will be position dependent because of the variation with position in the energy of particles entering E2. The pion energy will be calibrated similarly from the pulse heights in each element which fires.

Inelastic interactions of protons and pions in the scintillator will seriously affect the response of the detector. Measday [5] has calculated that for 100 MeV protons inelastic interactions will produce a tail on the pulse height response of scintillator with a tail/peak ratio of ~12%. This figure rises to ~35% at 200 MeV. Most of the events degraded will be higher energy protons which stop in E2. These may be identified and discarded if their $\frac{dE}{dx}$ signals in ΔE2 and E1 are inconsistent. In addition, if neutrons are produced in inelastic interactions with ^{12}C then ~30% of these will be detected and vetoed in E3 and E4. Corrections can be made to measured yields for such discarded events. Nevertheless a proportion of recorded events will have their energy degraded. Preliminary Monte Carlo calculations, based on the cross-sections used by Measday, have been used to calculate the shape of the tail in the detector response. These have given reasonable shapes and magnitudes for the effects and will be refined further. The response will also be checked experimentally using protons of known energy from the d(γ,p)n reaction. Even allowing that the response can be measured and modelled, inelastic interactions will probably limit the upper useful proton energy of the detector to ~200 MeV.

For pions inelastic interactions will be more severe. Simulations have shown losses rising from 20% at 50 MeV to 88% at 180 MeV. However the segmentation of the detector should allow even more of these events to be identified and discarded than for protons.

The PIP detector is now ready for final tests and calibration experiments which are planned to take place this summer. The first test will be to measure the response to cosmic rays. Next the background in the experimental hall will be measured. Measurements of the proton energy calibration and response will then be carried out using the d(γ,p)n reaction with tagged photons. Using the time-of-flight array to record correlated neutrons the pion response will be measured using the p(γ,π^+n) reaction.

References

[1] H. Herminghaus et al., proceedings Linear Accelerator Conference, Albequerque, 1990.

[2] I. Anthony et al., Nucl. Inst. and Meth. A301 (1991) 230.

[3] T. Hehl, ibid.

[4] I.J.D. MacGregor et al. Nucl. Inst. and Meth. A 262 (1987) 347.

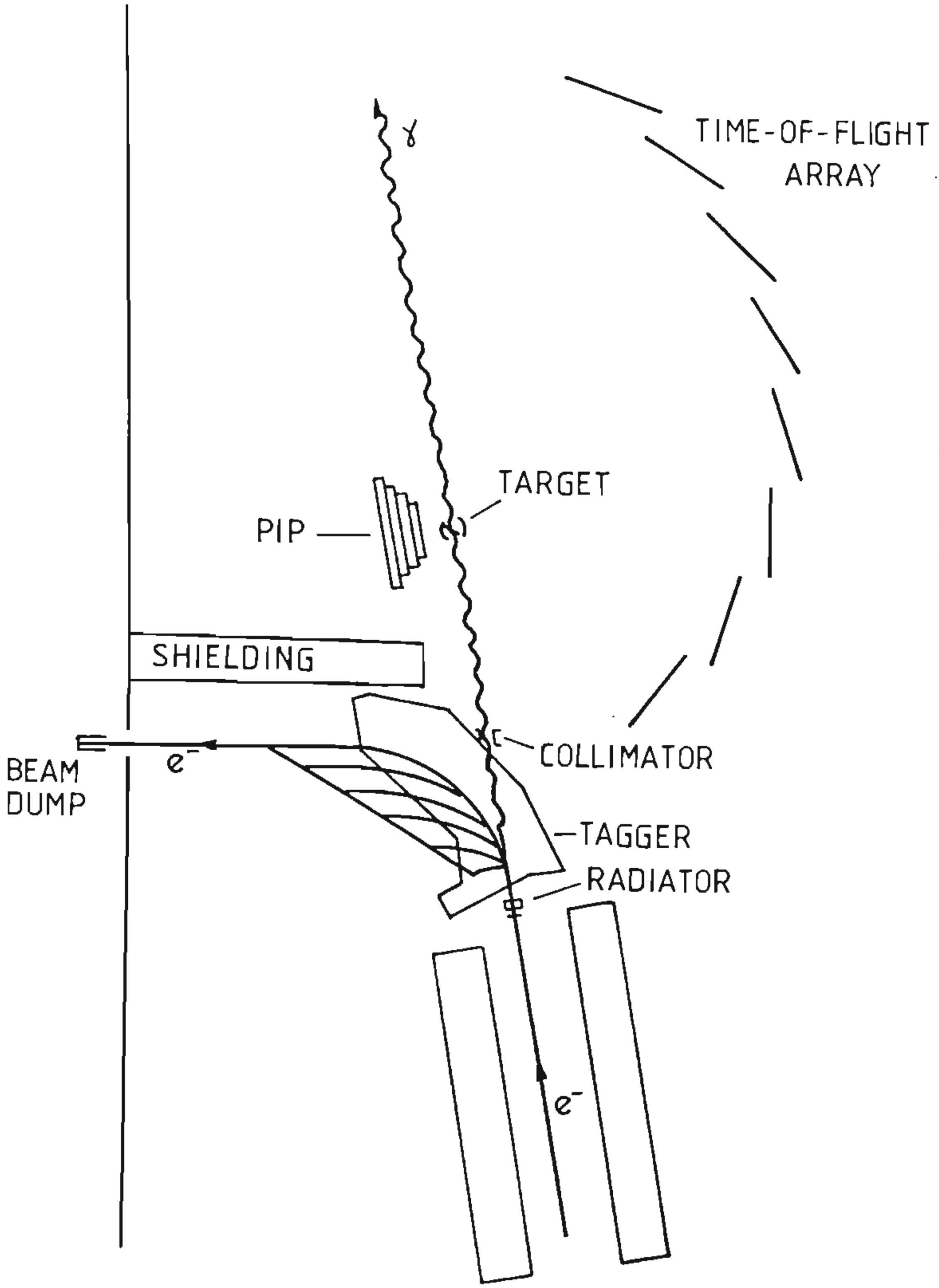
[5] D.F. Measday and C. Richard-Serre, CERN report CERN 69-17 (1969) p1.

Figure Captions

Figure 1. Layout of the Mainz tagged photon experimental hall.

Figure 2. Plan of PIP detector.

Figure 3. Schematic diagram of PIP electronics.



γ
TIME-OF-FLIGHT
ARRAY
TARGET
PIP
SHIELDING
BEAM
DUMP
e⁻
COLLIMATOR
TAGGER
RADIATOR
e⁻

FIG. 1.

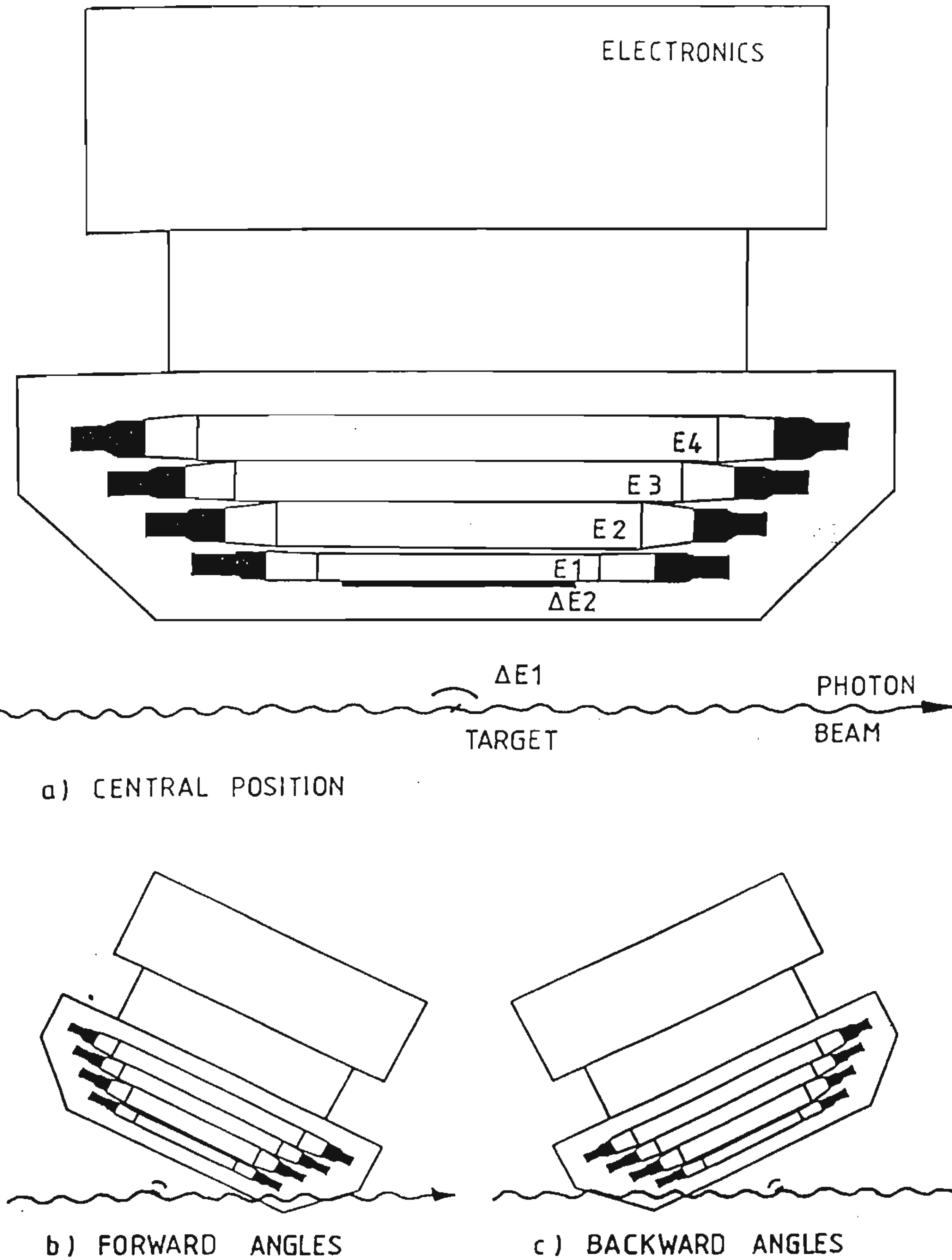

ELECTRONICS
E4
E3
E2
E1
ΔE2
ΔE1
PHOTON
BEAM
TARGET
a) CENTRAL POSITION
b) FORWARD ANGLES
c) BACKWARD ANGLES

FIG 2

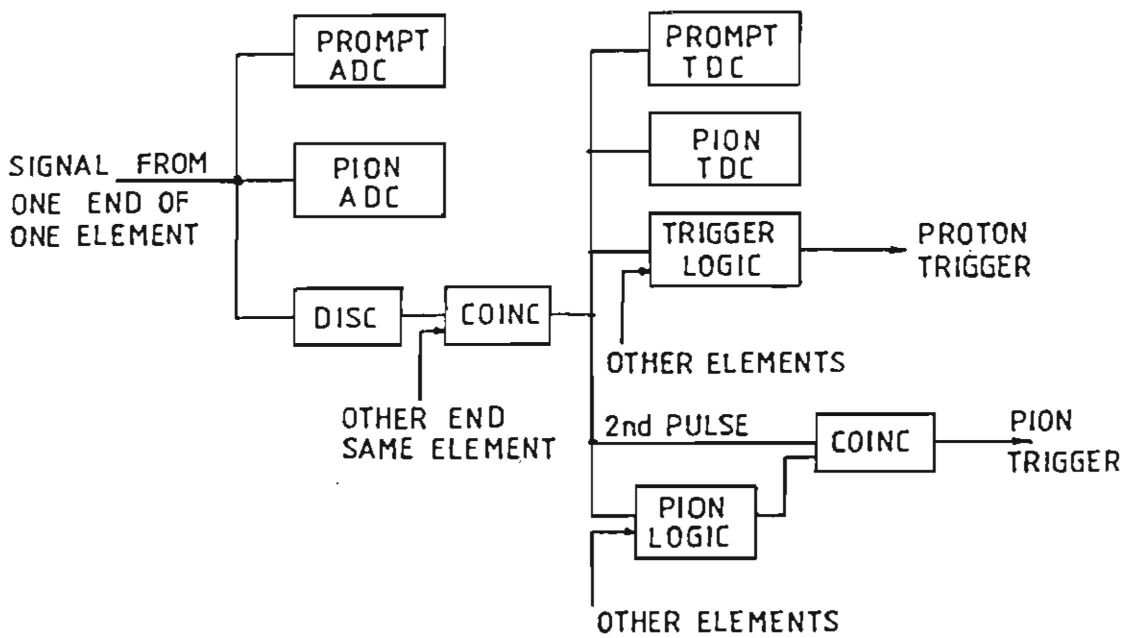

PROMPT ADC
SIGNAL FROM ONE END OF ONE ELEMENT
PION ADC
DISC
COINC
OTHER END SAME ELEMENT
PROMPT TDC
PION TDC
TRIGGER LOGIC
PROTON TRIGGER
OTHER ELEMENTS
2nd PULSE
COINC
PION TRIGGER
PION LOGIC
OTHER ELEMENTS

FIG. 3.